# Direct Wafer Bonding of Gallium-Arsenide to Sapphire

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High voltage (>100 V) circuits fabricated on the surface of gallium-arsenide (GaAs) wafers suffer from excessive electrical leakage through the wafer substrate. Formation or placement of isolated GaAs circuit elements on a dielectric substrate has been shown to break the electrical pathway between circuit elements through the substrate and enable operation of high-voltage devices. Bonding of GaAs to a dielectric substrate using adhesives is not robust enough to survive circuit processing. This work demonstrates an improved method to form a strong and stable bond between GaAs and sapphire that enables the formation of dielectrically isolated high-voltage circuit elements on GaAs using standard IC fabrication techniques.

## Project Goals

Our goal was to extend past successful efforts by LLNL's Laser Program (directly bonding GaAs to GaAs) to bonding GaAs to a dielectric material such as sapphire. Our specific goals included direct bonding of 2-in.-diameter wafers with sufficiently large void-free areas to enable the fabrication of complete high-voltage arrays of photodiodes, and bond strengths in excess of 1 $J/m^2$.

## Relevance to LLNL Mission

Optically powered, high-voltage power supplies have been identified as potential components of advanced firesets for DoD and DOE applications. Compact size, reduced parts count, and inherent electrical isolation are key advantages of photovoltaic power supplies. Direct (covalent) bonding of GaAs to an electrical insulator, such as sapphire, before the circuits are formed in the GaAs would provide a means to use low-cost integrated circuit production techniques to produce high-voltage circuits.

## FY2004 Accomplishments and Results

Wafers of GaAs were prepared with a 1-$\mu$m-thick etchstop layer of aluminum-gallium-arsenide (AlGaAs) followed by a 0.1-$\mu$m-thick layer of GaAs epitaxially grown on their surface. The wafers used had surface roughness < 0.2 nm rms, 5- to 8-$\mu$m flatness, and 3- to 8-$\mu$m bow. The orientation of the GaAs wafers was <100>. The orientation of the sapphire wafers was c-plane.

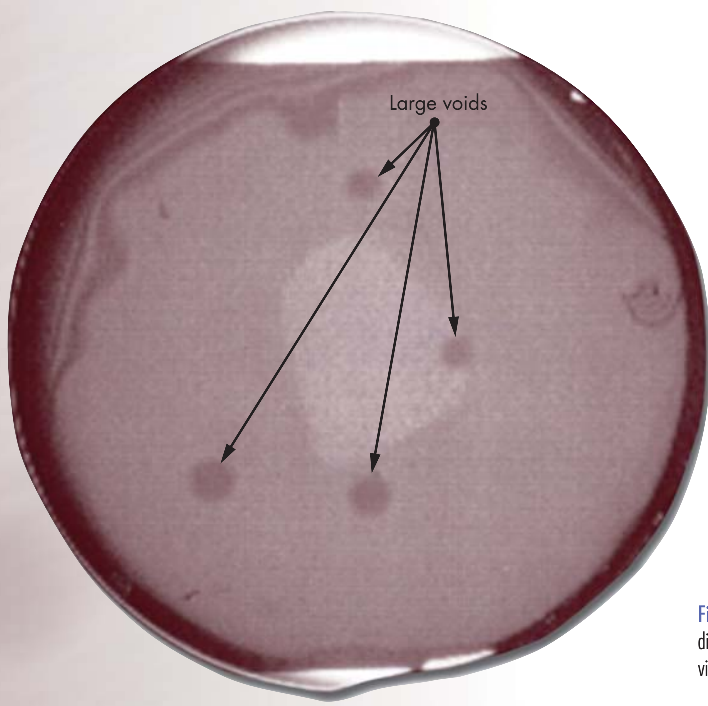


Figure 1. View of interface between 2-in.-diameter GaAs wafer and sapphire wafer as viewed through the sapphire wafer.

The bonds were formed using a carefully controlled cleaning and preparation process to minimize any particulate and molecular contamination of the surfaces to be joined. The final step before actually joining a GaAs wafer to a sapphire wafer was to clean each wafer at high temperature in flowing hydrogen gas. Typical GaAs clean was done at 720 °C as the final part of the epitaxial growth process; the sapphire clean was performed at 500 °C. The pressure was 60 torr and the hydrogen flow rate was about 2 L/min through a reactor area of 22 $cm^2$. After both wafers had been treated in hydrogen, they were manually brought into contact with each other at room temperature in an ultra-dry nitrogen environment. Localized mechanical pressure was used to bring the surfaces close enough together to obtain weak contact bonding by Van Der Waals forces. Most large voids, visible as interference fringes through the sapphire wafer, could be successfully collapsed using this technique. The joined pair was again treated to high temperature in hydrogen gas to form a stronger covalent bond.

Visual inspection of the bond interface obtained by bonding at 500 °C revealed the presence of voids of various sizes ranging from several millimeters to >100 $\mu$m in diameter (Figs. 1 and 2). The number of voids depended on void size, with few large voids and many semi-uniform small voids. The small voids were eliminated in subsequent bonds by use of an extended hydrogen purge and clean at 400 °C of the wafer surfaces in contact but without applied pressure, as well as a lower bond temperature of 400 °C after pressure contact. The largest bond area free of voids achieved to date is about 1.6 cm × 1.9 cm. One photovoltaic application requires a 1.4-cm-×-1.4-cm area for a complete array.

A test bond was used to obtain a quantitative measurement of the bond strength, using a wedge to pry the wafers apart.

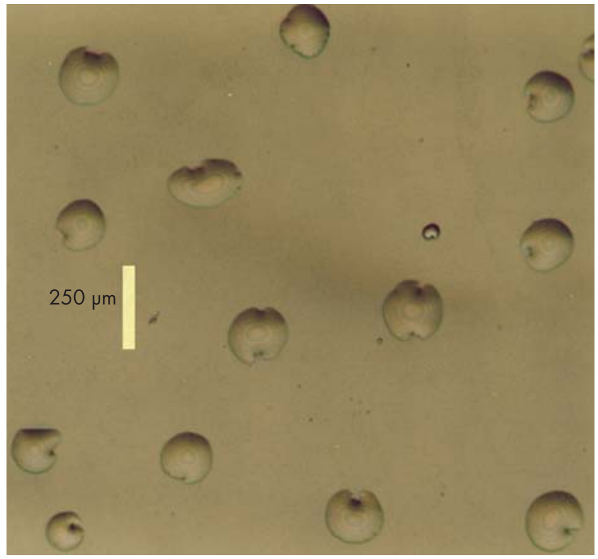


Figure 2. Microvoids visible on surface on first GaAs bond after removal of thick GaAs substrate.

Preliminary analysis of the data indicates a bond strength in the range of 0.71 $J/m^2$. Successful growth of thick GaAs on a layer of GaAs bonded to sapphire without obvious delamination or cracking is a strong indicator of the strength and robustness of the bond. Since no photovoltaic devices have yet been fabricated on GaAs bonded to sapphire, it is not known if crystalline defects were introduced into the grown GaAs film that would affect photovoltaic performance.